A GIS-based multi-criteria approach for finding urban growth directions: A case study in Siem Reap, Cambodia

CHANVOLEAK OURNG; DANIEL S. RODRIGUES and RUI A. R. RAMOS
Engineering School – Department of Civil Engineering
University of Minho
Campus de Gualtar, 4710-057 Braga
PORTUGAL
chanvoleak.ourng@gmail.com http://www.civil.uminho.pt/

Abstract: The main objective of this paper is to describe a methodology to estimate in which directions of urban expansion can occur in Siem Reap town, Cambodia. Three main urban driving force factors were identified: population density, distance to road networks, and distance to existing urban. Geographic Information System based multicriteria approaches were integrated to implement this research model. Fuzzyfication process was used to normalize data, allowing posterior aggregation. Analytical Hierarchy Process (AHP) pairwise comparison method was used to assign weights to each factor. This define hierarchy was integrated to map the direction of urban growth in Siem Reap by GIS spatial analyst tools.

Key-Words: - GIS, urban growth, multicriteria approach, normalization

1 Introduction

The definition of urban has differed across scientists as well as countries. Urban refers to a particular type of place where the economic concentration of non-agricultural activities and the social concentration of particular types of values, behavior, organization, and institutions are presented [1]. Understanding urban growth and change is critical to city planners and resource managers in these rapidly changing environments [2]. A number of analytical and static urban models have been developed based on diverse theories such as urban geometry, size, and relationship between cities, economic, functions, and social ethnic patterns with respect to city structures [3]. Land use in urban areas can frequently change, influenced by the construction of new buildings, roads, and other transformations. Temporal land use mapping and urban growth modeling are developed to explore the urban sprawl pattern, rate, and trend in land use change. A GIS-based multi-criteria method is developed and implemented as a case study in Siem Reap, Cambodia. The main objective of the work presenting in this paper is finding the direction of urban expansion which was influenced by population density, distance to road networks, and distance to existing urban area.

2 Research methodology

Several tools and functions of a GIS toolset were used to map the direction of urban expansions, such as rasterization, standardization, weighting, and datasets combination. Figure 1 represents graphically how this process was conducted.

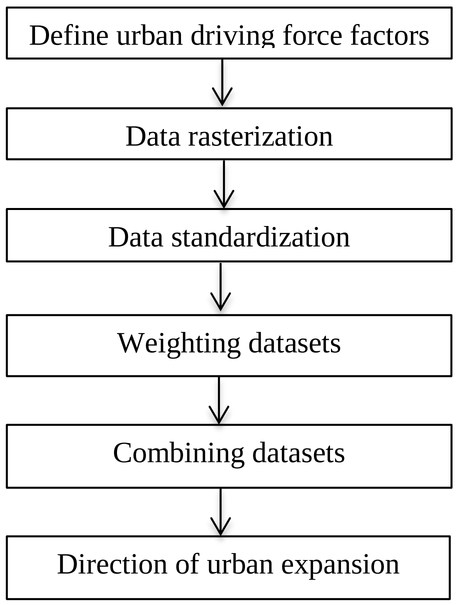

Figure 1: GIS-based multicriteria urban growth direction model

In the first step, rasterization, a GIS “vector to raster” conversion tool was used to produce raster data from vector inputs. Moreover, normalization is the process of transforming all the data to the same scale, allowing the subsequent aggregation. Analytical Hierarchy Process (AHP) was applied to

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calculate the weight of each factor to be used in the analysis. And the last step was combining datasets. At the end, with all values expressed on the same scale and applying different weights, data was combined to generate the map of urban growth direction.

2.1 Defining urban driving force factors

Urban driving force factors were selected from literature review and interviews with key experts during field visit. Five experts, who are involved or have knowledge in urban development from different sectors, were selected for interviewing. By this mean, it was possible to gather the contributions of persons from the Department of urbanization and urban planning, the District master plan, the Department of Angkor tourism development, the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA), and the Department of demography and development.

2.2 Data normalization

In multicriteria evaluation, Fuzzy set membership is used in the standardization of criteria. Exactly which function should be used will depend on the understanding of the relationship between the criterion and the decision set, and on the availability of information to infer fuzzy membership. In most case, either the sigmoidal or linear is sufficient. Because of the different scales upon which criteria are measured, it is necessary to standardize them before aggregation. The process of standardization is essentially identical to one of fuzzification in fuzzy sets [4]. Fuzzy set membership tool reclassifies or transforms the input data to a 0.0 to 1.0 scale based on the possibility of being member of a specified set. 0.0 is assigned to those locations that are definitely not a member of the specified set, 1.0 is assigned to those values that are definitely a member of a specified set, and the entire range of possibilities between 0.0 and 1.0 are assigned to some level of possible membership (the larger the number, the greater the possibility). The fuzzy membership tool allows you to transform continuous input data based on a series of specific functions that are common to the fuzzification process [4]. Depending on the characteristic of criterion being fuzzified, vary fuzzy fucntions can be selected among the most used; Sigmoidal (S-shaped), linear, J-shaped, and complex [5].

In this research, fuzzy linear membership function as shown in figure 2 below is used to transform the value linearly on the 0.0 to 1.0 scale, with 0.0 being assigned to the lowest value and 1.0 to the largest value. The fuzzy linear transformation function applies a linear function between the user-specified minimum and maximum values. Anything below the minimum will be assigned as 0.0 and anything above the maximum as 1.0.

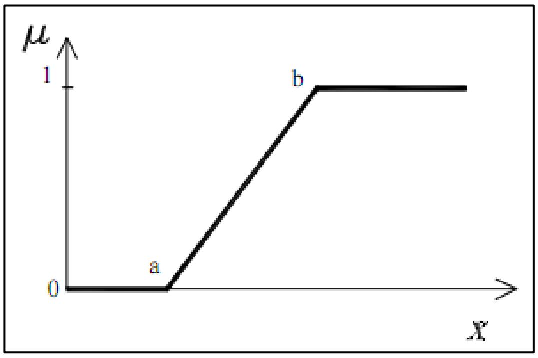

Figure 2: fuzzy set membership function (Linear)

The formula of fuzzy linear membership function is given below.

$$\mu = \frac{(x - x_a)}{(x_b - x_a)} \qquad \text{Equation 1}$$

Where

$x > x_b$, $\mu = 1$

$x < x_a$, $\mu = 0$

When fuzzifying distance variables, the S-shaped monotonically decreasing function as shown in figure 3 below is one of the most commonly used in fuzzy set theory [5]. It is produced using a cosine function.

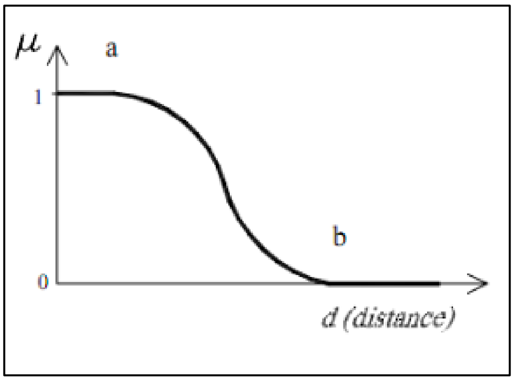

Figure 3: Fuzzy set membership function S-shaped

The equation of S-shaped is given below.

$$\mu = \cos^2(\alpha) \qquad \text{Equation 2}$$

$$\alpha = \frac{(d - d_a)}{(d_b - d_a)} * \frac{\pi}{2}$$

Where

$$d > d_b, \ \mu = 0$$

$$d < d_a, \mu = 1$$

Control points "a" and "b" are the critical points that should be set for each particular situation.

2.3 Analytical Hierarchy Process (AHP)

Among many methods to assign the weight established and used by different authors, two are most commonly used [5]: the n-points scale (originally seven points scale, as introduced by Osgood et al., [6]) and a complexity method called pairwise comparison, which was developed by Saaty [7]. Pairwise comparison approach known as AHP was used in the process of criteria weighting of each urban driving force factors. As the influences of urban growth factors may varied, different weights should be assigned. By this way, weights were used to express the importance of one factor related to another. Saaty developed AHP, which provides an efficient hierarchical process for decision making to estimate the importance of one factor related to another. It is considered an efficient process to select criteria, define their weights, and perform analysis, interviewing participants that have to compare the importance of factors, two at a time [7].

To assign the hierarchy of each factor, there are three main steps; comparison matrix generation, computation of criterion weights, and finally estimation of consistency ratio [7].

3 Model application

The methodology presented in the previous section was implemented on a case study in Siem Reap town, Cambodia. Siem Reap town is the capital city of Siem Reap province, which is located in the Northwestern part of the country. The study area is situated between 13°12' N to 13°29' N latitudes and 103°44' E to 103°56' E longitudes as shown in figure 4. It is surrounded by Oddar Meanchey province at North, Preah Vihear and Kampong Thom province at East, the Tonle Sap Lake at South, and at West by Banteay Meanchey province. Siem Reap has an area approximately 103,00 km2 and is composed by 12 districts.

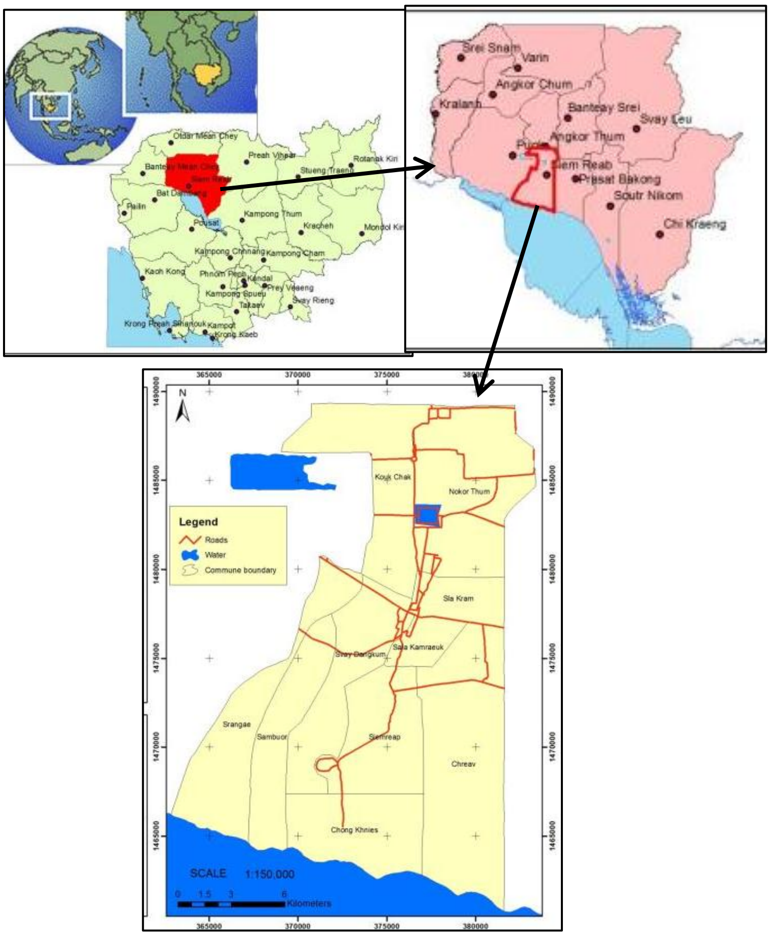

Figure 4: Map of selected study area

Siem Reap nowadays is a vibrant town with modern hotels and architectures. According to national socio-economic census in 2003 from National Institute of Statistic (NIS) of Cambodia, the total population of Siem Reap district was 126,820 with a density of 365 persons per square kilometers (sq.km) (NIS, 2003) [8]. However, the population increased gradually to 166,867 in 2008 with a density of 489 persons per sq.km (NIS, 2008) [8]. Moreover, in 2003, the number of housing was only 21,878 but in 2008, it increased gradually to 27,161 with 128 hotels, 1,174 guesthouses, and 219 restaurants in Siem Reap district (Census, 2008) [8]. Furthermore, in 1993 the number of tourists visiting Siem Reap was only 118, 183 but in 2010, the number of tourists increased significantly to 2,508,289. Thus, it can be projected that the number of tourist will raise continuously (Ministry of Tourism, 2010). Despite international influences, Siem Reap and its people have conserved much of the town's image, culture, and traditions. Because Siem Reap is an area of archaeological and world heritage, therefore royal government is concerned with the present situation because it may affect the physical and characteristic of archaeological heritage sites in Siem Reap district if the land use continues changing with improper plan.

3.1 Urban driving force factors in Siem Reap

From literature review, it can be seen that many factors can influence urban growth. Allen and Lu [9], presented 15 variables to measure physical suitability for urban growth in Charleston region South Carolina. Those criteria are existing land use, slope, wetland, distance to water front, distance to major node, distance to major roads, road density, distance to waterline, distance to sewer line, population density, cost distance to Central Business District (CBD), existing urban, distance to existing urban, corporate boundary, and protected land. Moreover, Jianquan Chen [10], which studied on urban growth pattern modeling in China revealed that the major urban growth factors are urban roads infrastructure and developed area. Ji han et al. [11], defined that road network played as an important role in directing the development of newly urbanized area. To be applied in the case of Siem Reap, urban growth factors were defined using the contributions of key experts during field survey. The result showed that the number of tourist is the major pushing factor of urban growth in Siem Reap, while the population density, road networks, and distance to existing urban area are the main urban driving force factors. Therefore, Pearson correlation statistics was applied to justify the relationship between the factors and the urban growth [12].

3.2 Data rasterization

The possible urban expansion direction, which is influenced by the three main urban driving force factors, was mapped by applying spatial analyst toolsets. The process is divided in four steps. First step is rasterization, “Conversion tools- Polygon to raster” was used to convert population density to raster and “Spatial Analyst tools-Distance-Euclidean distance” was used to calculate the distance from each cell in the raster to the closest source which was applied on distance to roads and distance to exiting urban area. Each factor was calculated by using Euclidean distance tool in term of finding the distance to each variable.

3.3 Data standardization

Because of each criterion have different scale, it is necessary to standardize them before aggregation. Therefore, fuzzy linear membership function is applied on population density factor with the purpose of converting to the scale 0.0 to 1.0. The formula to calculate fuzzy linear membership is denoted in equation 1 and is given as below.

Where

μ	is linear membership function
X	is population density (raster)
Xa = 8478	is the min. population density value
Xb = 296270	is the max. population density value

Therefore,

$$\mu = \frac{(X-8478)}{(296270-8478)}$$

If	X> 296270	then	μ=1
And if	X<8478	then	μ=0

However, when fuzzyfying distance variables, Sigmoidal (S-shaped) monotonically decreasing is used to apply on distance to roads and distance to existing urban area. The value to calculate S-shaped function from the equation 2 is given in the table 1 below.

Table 1: Criteria, fuzzy function, and the distance of maximum and minimum

Criteria	**Fuzzy function**	**Dist. a (km)**	**Dist. b (km)**
Distance to roads	Sigmoidal	0	2
Distance to existing urban	Sigmoidal	0	2

The selected minimum and maximum distance value was based on the Pearson correlation analysis which was used to justify the relationship between the growing force factors and urban area growth [12].

Where

μ	is S-shaped membership function
d	is Distance to roads and Distance to existing urban area (raster)
da = 0m	is the minimum distance value
db = 2000m	is the maximum distance value

Therefore,

$$\mu = \cos^2\left(\frac{d}{2000} \times \frac{\pi}{2}\right)$$

If	d> 2000m	then μ=0
And if	d<0m	then μ=1

3.4 Weighting datasets

A survey questionnaire form was prepared and applied to key experts to generate urban driving force factors. AHP was used to calculate the weight of each factor and combine them to find out the direction of urban expansion. The process of scoring the datasets is described below in table 2.

Table 2: Pairwise comparison of the evaluation urban growth criterion

Factors	Roads	Pop.	Exist. urban
Roads	1.000	3.000	5.000
Population	1/3	1.000	2.000
Exist. urban	1/5	1/2	1.000
Total	**1.533**	**4.500**	**8.000**

Table 2 reveals that the road networks are moderately preferred over the population density, which the numerical is 3. Moreover, the comparison result in a value of 5 shows that the road networks are strongly preferred to existing urban area. Finally, consider the only other pairwise comparison, which is population density compared to existing urban area reveals that former is equally to moderately preferred to latter, a score of 2.

Table 3: Computation the weight of the urban growth factors

Factors	Weight
Distance to Roads	0.647
Population density	0.229
Distance to Existing urban area	0.122

From pairwise comparison matrix in table 3 each factor has been normalized to get the weight. It illustrates that the criterion weights are 0.647, 0.229, and 0.122 for distance to roads, population density, and existing urban area respectively. This means that the distance to roads networks is the most important criterion, followed by population density, and existing urban area. After assigned the weights of each criterion, estimation of the consistency ratio is calculated to determine if the comparisons are consistent. It involves the following procedure.

Table 4: Determining the consistency vector

Factors	Weight sum vector	Consistency vector
Roads	1.948	3.007
Population	0.690	3.002
Existing urban area	0.366	3.001

The consistency vector have been calculated in table 4 which depicts the consistency vector of distance to roads, population density, and existing urban area are 3.007, 3.002, and 3.001 respectively. Next step is to compute the lamda (γ) and the consistency index (CI). The value for lamda is simply the average value of the consistency vector.

$$\gamma = \frac{3.007 + 3.002 + 3.001}{3} = 3.003$$

The consistency index (CI) is normalized as follows:

$$\mathrm{CI} = \frac{\gamma - \mathrm{n}}{\mathrm{n} - 1} = \frac{3.003 - 3}{3 - 1} = 0.001$$

The consistency ratio (CR) is defined as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = \frac{0.001}{0.580} = 0.003$$

The CI is designed in such a way that if CR <0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons. If, however, CR≥0.10, the values of the ratio are indicative of inconsistent judgments. RI is the random index, the consistency index of a randomly generated pairwise comparison matrix. It can be shown that RI depends on the number of elements being compared. The consistency ratio CR=0.003 < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons.

3.5 Mapping urban growth direction

The factors affected urban driving force in Siem Reap are distance to roads, distance to existing urban area, and population density. Therefore, the formula for mapping the directions of urban growth in Siem reap is given as:

$$\mathrm{U} = aX_1 + bX_2 + cX_3 \qquad \text{Equation 3}$$

Where,

U	Urban area
X1	Distance to roads
X2	Population density
X3	Distance to existing urban area
a, b, c	Weighting for each factors

So,

$$U_T = 0.647X_1 + 0.229X_2 + 0.122X_3$$

The result in figure 5 shows that urban expansion is more likely to happened in mainly four communes; Sla Kram, Chreav, Svay Dangkum, Sala Kamroeuk. The highest values (greener zones in map) correspond to areas where driving factors have a

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stronger influence, i.e., areas more susceptible to become urban. On the opposite, the lowest values (reddish zones in map) correspond to areas where the driving factors effect is weaker, i.e., areas where urban expansion is less. From the result of combining all the factors showed that the direction of urban could be expanded with the influence of high population density, distance to roads, and distance to existing urban area.

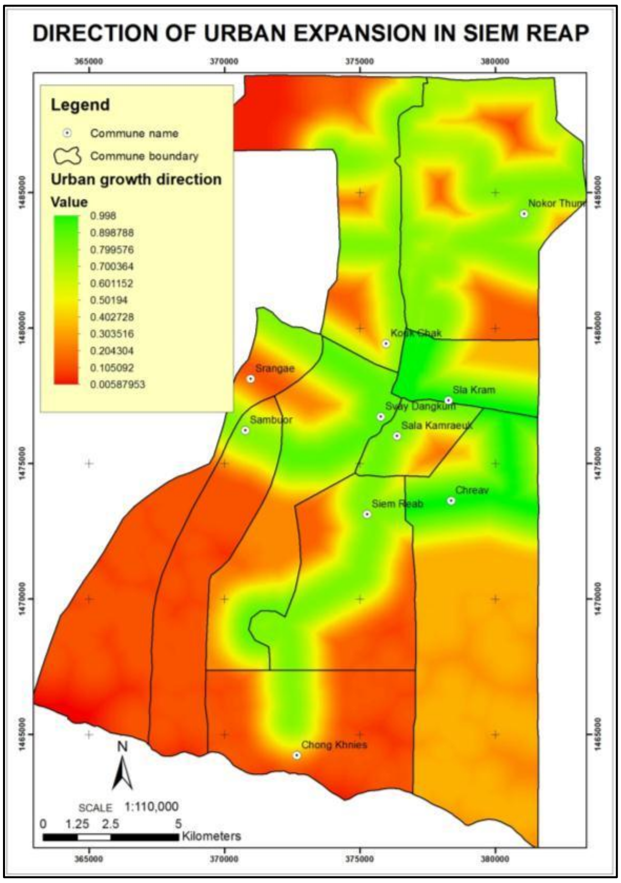

Figure 5: Direction of urban expansion, Siem Reap

4 Conclusion

A methodology has been proposed and carried out by integrating complex theory, modeling, RS, and GIS technique. The combination of literature review and interview with key experts during field visit found that there were three urban growth factors in Siem Reap. Those are distance to road networks, population density, and distance to existing urban area which plays as an important role in directing urban growth. GIS-based multi-criteria approaches; fuzzy set membership function, AHP, and GIS spatial analysis tools were integrated to implement this research model. The analysis to determine the possible direction of urban expansion in Siem Reap can help planners to understand where urban expansion would be located. The model is intended to provide a vision of the future, working as a tool to help increase environmental awareness. Future development should conclude with the proposal of policies to maintain sustain balance between urban and non-urban area.

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